Shock Passage Over an Interface

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When a shock passes over an interface between two materials, the result is an instability that produces growth of fine-scale perturbations. A consequence is the interpenetration of each material into the other to form a growing mix layer. To describe theoretically how this dynamical process occurs, investigators perform numerical experiments by solving finite-difference approximations to the equations of fluid dynamics. One type of calculation follows with fine resolution the detailed behavior of a specific initial configuration, including the three-dimensional structure of the perturbations. Some results from a resolved calculation of a shock passing over an initially perturbed interface are shown in Figs. 1 and 2. Another technique uses turbulence transport equations to describe the ensemble-averaged behavior of mix-layer growth, while a third procedure is based on a two-field approach that describes the motion of fluid globules through and past each other.

For many applications the detailed resolution of perturbation response is too costly for practical problem solving. On the other hand, turbulence transport equations and two-field representations are of questionable validity for an accurate description of what is going on. To attain sufficient accuracy we use a combined theoretical and experimental program. Los Alamos National Laboratory's (LANL's) Theoretical (T) Division contributions to this program consist of complementary calculations with the turbulence transport equations and the two-field equations, close collaborations for the design and analysis of experiments performed with the gas curtain apparatus in LANL's Dynamic Experimentation Division, and interactions with investigators in other divisions of the Laboratory who are also examining the applicability of calculation techniques to representative problems.

In both types of the T-Division calculations the mean flow dynamics within the interface are examined with very fine resolution. The initially perturbed structure is described by a postulated uniform variation of ensemble-averaged fluctuations in density. For the single point mean scale of the fluctuations, S, we choose a distance corresponding to the dominant size in the directions parallel to the nominal surface. A necessary property of

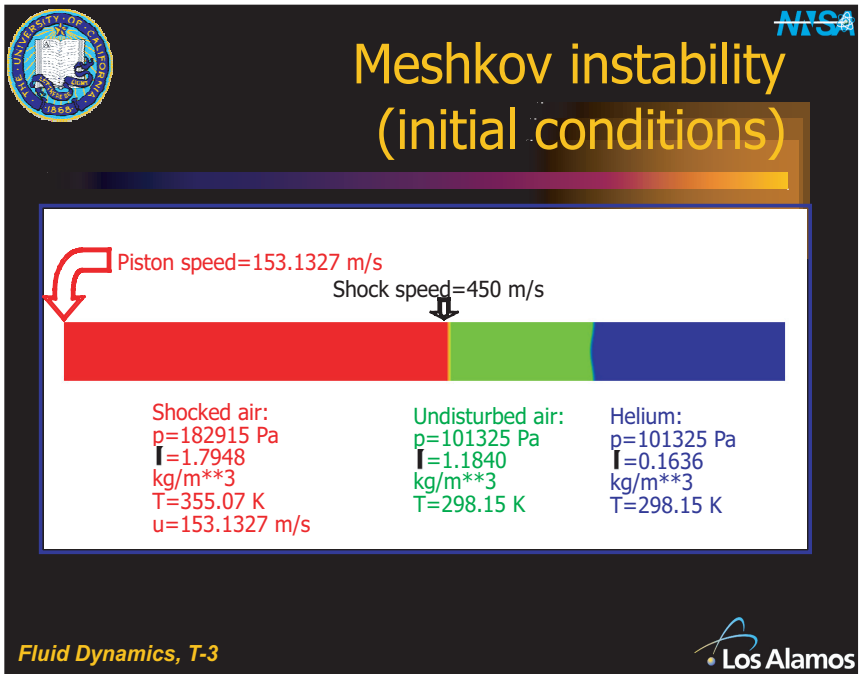

Figure 1 *— Schematic of initial conditions for shock-perturbed interface calculation. The shocked air on the left will interact with the air-He interface to amplify the initial interface perturbation.*

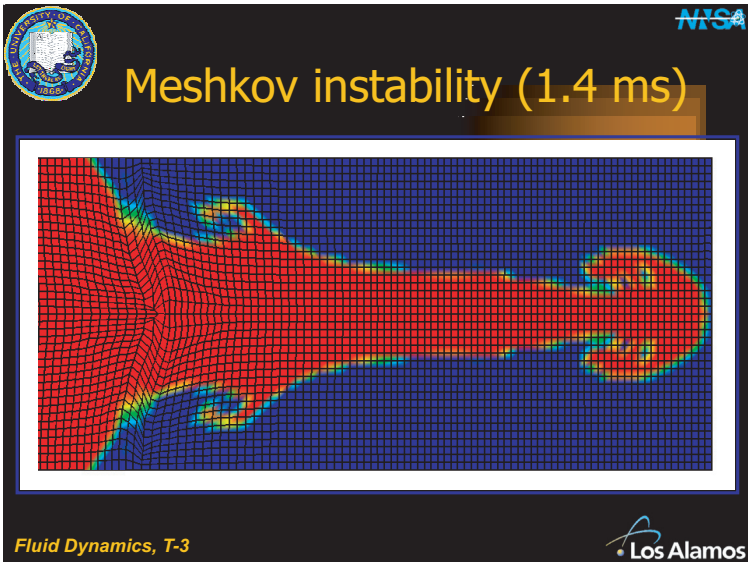

Figure 2—
At 1.4 ms, the shocked air has penetrated the helium and the mix width has grown dramatically. The background computational mesh is shown in black, and colors indicate the material type (red = air).

the calculation results is mesh convergence, i.e., asymptotic approach to a result that is independent of the finite-difference cell size as that size becomes small. But does the converged value for mixing rate agree with what actually happens in the laboratory? As we wait for accurate experimental data, we compare results from the transport approach with those of the two-field approach. If the converged results of these very different techniques are essentially the same, we develop confidence that the calculations may indeed be correct.

As an example of what we are learning, we have found that mesh convergence for the transport approach requires that the scale, S, does not change appreciably during and after the transit of the shock through the layer. This result is consistent with our expectations that the dominant scale transverse to the mean flow is nearly constant as the shock interacts with the perturbed interface. For many other circumstances in which turbulence is developed, the value of S changes rapidly, decreasing as the turbulence is driven by mean-flow gradients and growing after the driver recedes in strength. Because our turbulence transport equations were developed for this latter class of circumstances we conclude that a significant modification to the transport equation for S is required for shock-interface investigations.

The two-field formulations are well understood but require several additional parameters to model mass, momentum, and energy exchange between phases. Such exchange rates depend very strongly on the flow regime and are almost always determined through indirect experimental measurements. However, a two-field approach is computationally tractable even for full-system calculations and has been successfully applied to track fluid globules in the past. We are applying this approach to study the mixing of materials in the presence of shocks.

Theoretical Division is also developing a program to apply and test our turbulence transport equations for astrophysical investigations. In particular, we are calculating the interaction of a supernova shock with nearby, primordial gas clouds confined within dark matter potential wells [1]. The goal is to examine the mixing of supernova ejects (metals) with pure hydrogen/helium gas, in order to explain both the very uniform metallicity among the ~106 stars of an individual globular cluster and the considerable variation in metallicity from cluster to cluster in a galaxy.

[1] E. Scannapieco, J. Weisheit, and F. Harlow, "Triggering the Formation of Halo Globular Clusters with Galaxy Outflows," Los Alamos National Laboratory report LA-UR-04-2665 (to be published in *Astrophys. J.*).